DIRECTIVE FOR MONITORING THE IMPACT OF SULPHUR DUST ON SOILS

December, 2011

Government of Alberta

ISBN: 978-0-7785-9619-6 (Printed Edition)
ISBN: 978-0-7785-9620-2 (On-line Edition)
Website: http://environment.gov.ab.ca/info/

Directive for Monitoring the Impact of Sulphur Dust on Soils

December, 2011

Alberta Environment and Water

Any comments, questions or suggestions regarding the content of this document may be directed to:

Air, Land and Waste Policy Branch
Policy Division
Alberta Environment and Water
10th Floor, Oxbridge Place
9820-106 Street
Edmonton, Alberta, T5K 2J6
Fax: (780)-422-4192
Email: land.management@gov.ab.ca

Additional copies of this document may be obtained by contacting:

Information Centre
Alberta Environment and Water
4th Floor, Twin Atria Building
4999 -98 Avenue
Edmonton, Alberta, T6B 2X3
Phone: (780)-427-2700
Fax: (780)-422-4086
Email: env.infocent@gov.ab.ca

Table of Contents

Content **Page**

Introduction **1**
Background 1
Regulatory Purpose 1
Scope and Application of this Directive 1
Structure of this Directive 2
Requirements for Site Characterization, Monitoring and Mitigation 4

1. Common Types of Sulphur Manufacturing, Processing and Storage Operations in Alberta **5**
1.1. Overview of Common Types of Sulphur Manufacturing, Processing and Storage Facilities in Alberta 5
1.2. Operations Requiring Soil Monitoring for Deposition of Sulphur Dust 6
1.3. Operations Exempt from Soil Monitoring for Deposition of Sulphur Dust 6

2. Baseline Site Characterization Program **7**
2.1. Objective of the Baseline Site Characterization Program 7
2.2. Program Design for the Baseline Site Characterization 7
2.2.1. Site description 7
2.2.2. Soil sampling 7
Radial transect soil sampling design 8
Sampling locations 8
Sampling depth 10
2.2.3. Sample handling 10
2.2.4. Analytical parameters and methods 10
2.2.5. Laboratory analysis requirement 12
2.3. Requirements for the Baseline Site Characterization Program Report 12

3. Routine Monitoring Program **14**
3.1. Objectives of the Routine Monitoring Program 14
3.1.1. Requirements for the Routine Monitoring Program 14
3.2. Program Design for the Routine Monitoring Program 14
3.2.1. Soil sampling 15
3.2.2. Analytical parameters and methods 15
3.2.3. Operational thresholds for mitigation 16
3.3. Monitoring and Reporting Schedule for the Routine Monitoring Program 16
3.3.1. Monitoring 16
3.3.2. Reporting 17
3.4. Requirements for the Routine Monitoring Program Report 17

4. Mitigation Program **19**
4.1. Objectives of the Mitigation Program 19
4.2. Requirements for the Mitigation Program 20

4.3. Possible Strategies for Source Control 20
4.4. Strategies for Delineation 21
4.4.1. Soil sampling for delineation 21
4.4.2. Interpretation of analytical parameters for delineation 23
4.5. Soil Treatment 23
4.6. Confirmatory Sampling 24
4.6.1. Soil sampling 24
4.6.2. Analytical parameters and their interpretation for confirmatory sampling 24
4.7. Managing Outcomes of the Mitigation Program 25
4.7.1. Possible targets in different phases of a Mitigation Program 25
4.7.2. Adaptive management for the Mitigation Program 26
4.8. Requirements for the Mitigation Program Report 26

References 28

List of Table and Figures

Table 1 Recommended analytical methods 11

Figure 1 Relationships among the three programs in the Directive for Monitoring the Impact of Sulphur Dust on Soils 3

Figure 2 Radial transect sampling design diagram 9

Figure 3 Typical grid sampling design diagram 22

INTRODUCTION

The *Directive for Monitoring the Impact of Sulphur Dust on Soils*, hereafter referred to as the *Directive*, specifies the regulatory requirements by Alberta Environment and Water (AEW) for soil monitoring and mitigation activities that may be required when sulphur manufacturing, processing or storage facilities in Alberta have the potential to release sulphur dust to soils.

Background

Elemental sulphur is a by-product of hydrocarbon processing in upstream oil and gas plants, oil sands plants, bitumen upgraders and oil refineries. There is a risk of soil acidification from deposition of sulphur dust at and near plant sites that handle solid elemental sulphur. Sulphur accumulation in soils may also cause acidification of ground and surface water and consequently damage sensitive ecosystems. Remediation can be costly and difficult when soil acidification expands to large land areas or spreads to other media. Regulatory requirements and professional guidance are required to ensure that soils and associated environmental media are protected at and near these industrial plants and activities, approved by AEW under the *Environmental Protection and Enhancement Act* (EPEA) to handle solid elemental sulphur.

Alberta Environment and Water established monitoring and mitigation programs for deposition of sulphur dust and its impact on soils through the *Soil Monitoring Guidelines* under the *Air Monitoring Directive* (AENV, 1989). Technical innovations in the sulphur-handling industry over the past twenty years have reduced releases (Maynard et al., 1994, Crawford, 2009, and ERCB, 2010). Alberta Environment and Water has also been improving monitoring and reporting programs to enhance regulation of the industry. Consequently, an update of the *Soil Monitoring Guidelines* under the 1989 *Air Monitoring Directive* was required. The result is this *Directive*.

Regulatory Purpose

This *Directive* amends and replaces the *Soil Monitoring Guidelines* under the 1989 *Air Monitoring Directive*. The main purpose of this *Directive* is to provide clear direction on assessment and mitigation of the effects of deposition of sulphur dust on soil.

This *Directive* specifies regulatory requirements and provides professional guidance to conduct a Baseline Site Characterization Program, a Routine Monitoring Program and a Mitigation Program when required by an approval issued under EPEA.

Scope and Application of this *Directive*

The substance addressed by this *Directive* is elemental sulphur when it is deposited on soils in the form of sulphur dust. The *Directive* is intended to be used in conjunction with Alberta's existing regulatory framework as outlined in EPEA and relevant regulations, standards and guidelines such as *Alberta Tier 1 Soil and Groundwater Remediation Guidelines* (AENV, 2010a) as amended, *Alberta Tier 2 Soil and Groundwater Remediation Guidelines* (AENV, 2010b) as amended, and individual EPEA approvals.

This *Directive* focuses on lands in the vicinity of plants that handle solid elemental sulphur. It may also extend to selected locations within the boundary of a plant site when the overall pattern of deposition of sulphur dust needs to be assessed. However, monitoring for the release of sulphur to soil within the plant boundary and releases of other substances to soils in general, is otherwise addressed by the approval and the *Soil Monitoring Directive* (AENV, 2009), as amended.

Monitoring and mitigation of the impacts of sulphur dust on vegetation, groundwater and surface water, or from deposition of gaseous sulphur compounds, are outside the scope of this *Directive*. Information on those programs may be found elsewhere, for example, in *Sulfur Impacts on Forest Health in West-Central Alberta* (Maynard et al., 1994), *The Effects of Acidic Deposition on Forested Soils* (Robarge and Johnson, 1992), *Recommendations for the Acid Deposition Management Framework for the Oil Sands Region of North-East Alberta* (CEMA, 2004), *Site-Specific Critical Loads of Acid Deposition on Soils in the Provost-Esther Area, Alberta* (Turchenek and Abboud, 2001) and other sections of the *Air Monitoring Directive* (AENV, 1989), as amended. Alberta Environment and Water expects approval holders and their consultants to exercise sound professional judgement and due diligence when they investigate those media. Communication with regional staff at AEW will ensure that solutions are found for site-specific issues.

This *Directive* applies to the monitoring and mitigation programs for operating plants but does not address the final decommissioning and reclamation at these sites. Those activities are normally addressed through amendment of the approval when a plant approaches regulatory closure.

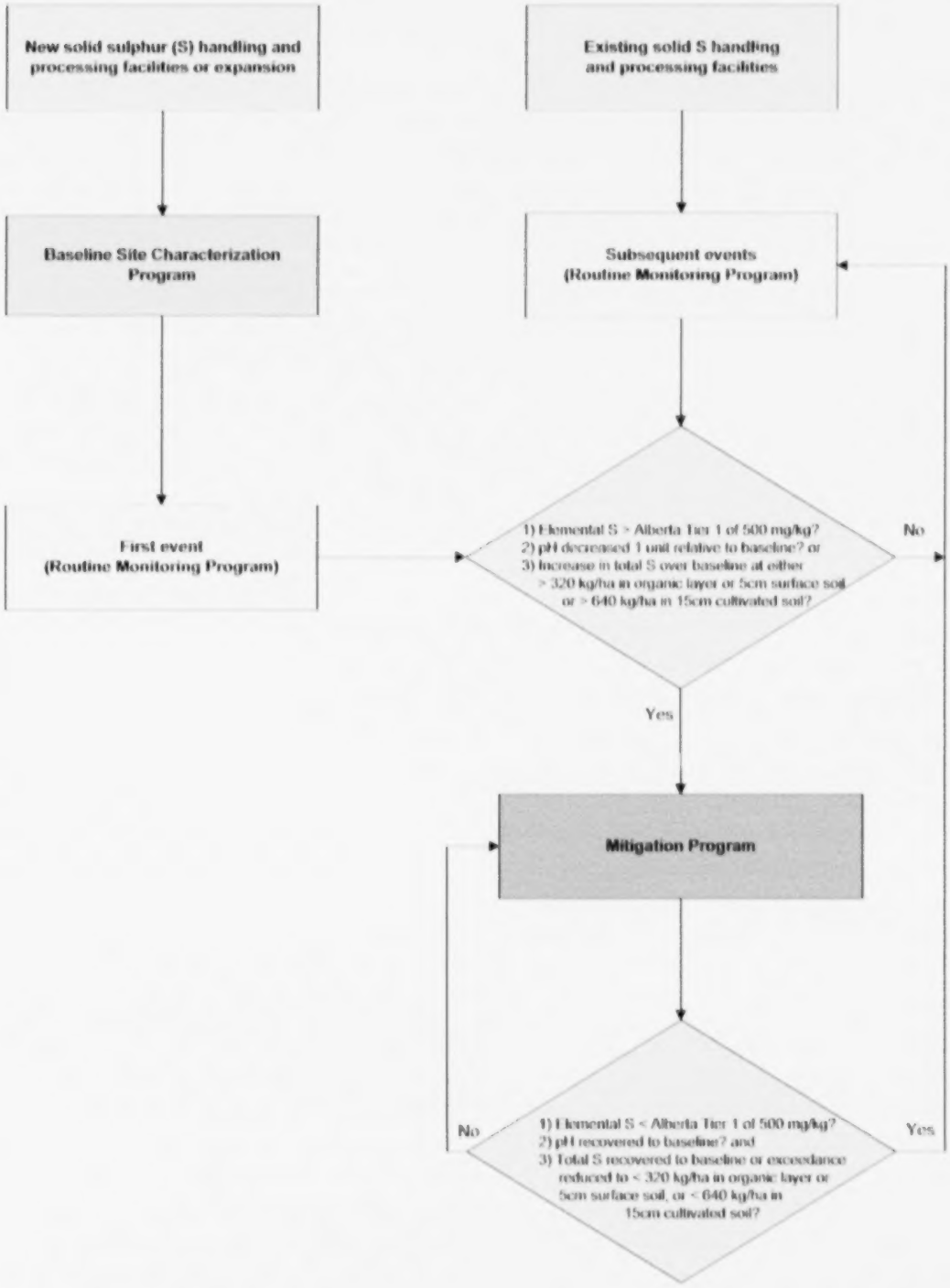
Structure of this *Directive*

This *Directive* is comprised of four major sections:

- Section 1: Common Types of Sulphur Manufacturing, Processing and Storage Operations in Alberta;
- Section 2: Baseline Site Characterization Program;
- Section 3: Routine Monitoring Program; and
- Section 4: Mitigation Program.

Section 1 of the *Directive* provides a high-level classification of common sulphur manufacturing, processing and storage operations in Alberta and identifies the types of industries where monitoring for the potential impact from deposition of sulphur dust is typically required. Section 2 describes the characterization of site conditions that must be conducted prior to commencement of sulphur operations at a new plant site or a plant expanding its operation to include sulphur handling. Section 3 specifies the monitoring program intended to detect deposition of sulphur dust and consequent soil acidification. Section 4 describes practical mitigation measures and confirmatory sampling required to assess and manage the outcomes of mitigation. The relationships among the foregoing three programs are outlined in Figure 1.

Figure 1 Relationships among the three programs in the *Directive for Monitoring the Impact of Sulphur Dust on Soils*


New solid sulphur (S) handling and processing facilities or expansion
Existing solid S handling and processing facilities
Baseline Site Characterization Program
Subsequent events (Routine Monitoring Program)
First event (Routine Monitoring Program)
1) Elemental S > Alberta Tier 1 of 500 mg/kg?
2) pH decreased 1 unit relative to baseline? or
3) Increase in total S over baseline at either
> 320 kg/ha in organic layer or 5cm surface soil
or > 640 kg/ha in 15cm cultivated soil?
No
Yes
Mitigation Program
1) Elemental S < Alberta Tier 1 of 500 mg/kg?
2) pH recovered to baseline? and
3) Total S recovered to baseline or exceedance
reduced to < 320 kg/ha in organic layer or
5cm surface soil, or < 640 kg/ha in
15cm cultivated soil?
No
Yes

Requirements for Site Characterization, Monitoring and Mitigation

Regulatory requirements in this *Directive* include provisions that are specifically linked to an approval and hence enforceable. Professional guidance is also provided to assist in fulfilment of the regulatory requirements. In this *Directive*:

- **shall** or **must:** denotes a mandatory requirement, and
- **should** or **may:** refers to professional guidance from AEW.

Prevention of the release of sulphur dust, to the extent practical, is the first step in protecting soils in the vicinity of sulphur handling and processing plants in Alberta. Approval holders are expected to make improvements and adopt the best available technologies to minimize the release of sulphur dust. As a participant in the Canadian Council of Ministers of the Environment (CCME), AEW advocates mitigation to the lowest concentration possible for any contaminant. Alberta Environment and Water promotes responsible environmental practices and does not accept the action of polluting up to a limit (AENV, 2010a). Approval holders must ensure that their operational practices are continually evaluated and improved. If the Routine Monitoring Program detects cumulative release of sulphur, mitigative measures must be taken, including at a minimum, source control, even when measured soil parameters are below the operational thresholds values identified in section 3.2.3.1 of this *Directive*.

Some soils in Alberta are sensitive to acid deposition including that resulting from deposition of sulphur dust. New sulphur handling and processing plants must be planned to avoid these sensitive soils. For existing plants, any indication of impact to sensitive soils should trigger mitigative actions.

1. COMMON TYPES OF SULPHUR MANUFACTURING, PROCESSING AND STORAGE OPERATIONS IN ALBERTA

Facilities where sulphur dust may be released are denoted in EPEA under the *Activity Designation Regulation* as 'sour gas processing plant', 'sulphur manufacturing or processing plant' or 'sulphur storage facility'. For the purpose of this *Directive*, they are collectively called sulphur handling and processing facilities. The risk of sulphur release to environmental media varies with the type of facility. In this section, AEW does not intend to provide an exhaustive discussion of all sulphur handling and processing facilities but rather to establish a practical link between this *Directive* and common types of sulphur operations in Alberta. Comprehensive reviews of those operations and their potential impacts on the environment can be found elsewhere, such as the publications by Robarge and Johnson (1992), Maynard et al. (1994) and Crawford (2009).

1.1. Overview of Common Types of Sulphur Manufacturing, Processing and Storage Facilities in Alberta

Sulphur manufacturing, processing or storage is often an integral part of the upstream oil and gas, oil sands, bitumen upgrading and oil refining industries in Alberta. For consumer safety and protection of the environment, various sulphur compounds must be removed from natural gas and petroleum products before they can be marketed. The most widely adopted method for sulphur removal currently used by industry is the modified Claus Process which converts hydrogen sulphide (H_2S) into liquid elemental sulphur. The latter is a major raw material for other industries such as chemical and fertilizer manufactures. Sulphur manufacturing, processing and storage operations in Alberta make the province a major global supplier of elemental sulphur.

Sulphur handling and processing operations generally include the following broad categories:

- storage facility;
- forming facility; and
- loading facility.

Storage facilities for solid elemental sulphur generally include blocks, open stockpiles and silos. Sulphur blocks are built by pouring liquid sulphur into moulds and allowing them to cool and solidify. The blocks are poured or re-melted depending on market demand for elemental sulphur. Open stockpiles are used to store solid elemental sulphur generated by an operation or transported from another plant. Silos are constructed to store formed elemental sulphur products before they are transported to intended markets. Pits provide temporary storage for liquid elemental sulphur, while tanks are used as primary storage.

Liquid elemental sulphur solidifies at approximately 119°C. The storage and transportation of liquid elemental sulphur requires heated equipment, which can be costly if sulphur products are to be distributed to the global market. Solid elemental sulphur produced as fine particles is subject to loss as air-borne dust during storage and transportation, which is also undesirable. Hence liquid sulphur and fine particles of solid sulphur need to be converted to solid products of suitable size to facilitate long-distance distribution to the global market.

A forming facility is used to conduct the conversion process. Common types of forming facilities include air prilling, GX granulation, rotoforming and slating facilities. In an air prilling facility, liquid sulphur is sprayed as liquid drops from the top of the prilling tower. Upward-moving air that is blown into the bottom of the prilling tower cools the liquid drops and converts them to granules of solid elemental sulphur called prills. Some sulphur is emitted from the top of the prilling tower as air-borne dust and dispersed downwind. The GX granulation facility involves a size enlargement process in which liquid sulphur is sprayed onto tiny nuclei or seeds of solid elemental sulphur inside a large rotary drum in a contained area and then cooled to a solid state. Repeated spray of liquid sulphur and cooling cause the nuclei of elemental sulphur to form into large, marketable solid granules. A limited amount of sulphur dust is released through the air outlet of the processing unit. The Sandvik rotoform process combines the rotoformer drop depositor with a steel belt cooler to create a system capable of producing sulphur pastilles of highly uniform shape, stability and quality. With a slating facility, liquid sulphur is spread onto a slow moving conveyer belt and cooled by water and air to form sheets of solid sulphur. The sheets are then broken into smaller pieces called slate, a product suitable for transport to end markets. Minor amounts of sulphur, in vapour form, are lost to the environment during the process. When an adequate volume of solid or liquid elemental sulphur is produced at a facility, it is loaded to truck or rail car and transported to market or a centralized storage facility.

Sulphur dust emissions usually derive from the handling of solid elemental sulphur during the mechanical breaking of sulphur blocks, the air prilling process and loading/unloading activities, particularly on windy days.

1.2. Operations Requiring Soil Monitoring for Deposition of Sulphur Dust

Alberta Environment and Water requires soil monitoring for the deposition of sulphur dust for those facilities which have this requirement in their EPEA approval. If this requirement is in a facility approval, the approval holder must follow the requirements set out in this *Directive*.

This requirement typically applies to those facilities that handle and process solid elemental sulphur using blocks, base pads, prilling towers, granulating facilities and loading/unloading facilities, or that store more than 100 tonnes of solid elemental sulphur.

1.3. Operations Exempt from Soil Monitoring for Deposition of Sulphur Dust

If an approval holder has handled only liquid elemental sulphur since commencement of plant operations, the plant is exempt from the monitoring and mitigation activities set out in this *Directive*.

If an approval holder handled or stored solid elemental sulphur on a commercial scale (i.e. more than 1.0 tonne per day or stored more than 100 tonnes) in the past but no longer does so, the approval holder can apply to the regional Director for exemption. An exemption may be granted if the approval holder provides data indicating that any adverse effect from sulphur dust to soil and related media has been successfully remediated and the analytical results meet the applicable standards at the time of remediation.

2. BASELINE SITE CHARACTERIZATION PROGRAM

This section is designed for approval holders at new sulphur handling and processing plants or where existing operations are being expanded to include the foregoing operations.

Soil pH and sulphur concentration vary considerably in native soils in Alberta and the pH in some forested soils is frequently below the range of the generic Alberta Tier 1 Guidelines (AENV, 2010a). Furthermore, sulphur is present in compounds other than elemental sulphur. Baseline soil pH values and total sulphur content have been used to define the operational thresholds for mitigative requirements (AENV, 1989) and are incorporated into the operational thresholds in this *Directive*.

2.1. Objective of the Baseline Site Characterization Program

The objective of the Baseline Site Characterization Program is to provide a data set that describes the soil conditions prior to the commencement of the operation of a new plant or expansion. The results of this program provide a basis for the operational threshold values in section 3 and possible soil targets for mitigation in section 4 of this *Directive*.

2.1.1.1 Prior to the commencement of the operation of a new plant or a plant expansion to include solid sulphur handling and processing operations, the approval holder shall conduct a Baseline Site Characterization Program in accordance with this Directive.

2.2. Program Design for the Baseline Site Characterization

The Baseline Site Characterization Program must be carried out in a timely fashion so that the results can be used to inform the first Routine Monitoring Program event that is required to be completed within the first two years of operation. The information collected during the Baseline Site Characterization Program is described below and reporting requirements are found in section 2.3 of this *Directive*.

2.2.1. Site description

The site description must provide the information on the sulphur operation and the environmental setting adjacent to the plant. The required information is set out in section 2.3. Information about the plant is focused on the potential release of sulphur dust while information about the environmental setting is related to possible deposition of sulphur dust. The Baseline Site Characterization Program must also identify any soils with characteristics that make them sensitive to acid deposition. The environmental setting and types of land use must be described over a distance of at least two kilometres from the plant boundary.

2.2.2. Soil sampling

The soil sampling design in the Baseline Site Characterization Program is described below and will be carried forward into the Routine Monitoring Program.

Radial transect soil sampling design

The radial transect design has been retained for soil sampling in the current *Directive*. It is intended to identify the locations where deposition of sulphur dust is likely to occur (AENV, 1989). The radial transect design based on predominant atmospheric conditions (i.e. stability and wind speed) in Alberta is illustrated in Figure 2. All sampling locations are situated outside the boundary of the plant.

The spatial extent of the sampling program will vary with the type of sulphur operation. For operations that utilize a prilling tower, the configuration of the sampling area is approximately elliptical in shape. Eight radial transects begin at the center of the main source(s) of sulphur dust and extend outward in all directions at 45 degree angles to a distance of 1000 m or 2000 m. Soil sampling locations are situated along each of the eight transects at 500 m intervals from the centre of the main source(s). An additional soil sampling location is situated along each transect at 50 m from the plant boundary. If a particular plant boundary places this sampling location too close to the adjacent sampling location 500 m away from main source(s), the former may substitute for the latter. The principal transect aligns with the predominant wind direction and extents downwind from the plant site. Sampling locations on this transect are recommended at approximately 500, 1000, 1500 and 2000 m. The two transects at 45 degree angles from the principal transect should be 1500 m in length. All remaining transects should be 1000 m in length. For operations without a prilling tower, the sampling area will usually be circular in shape with a radius of 1000 m.

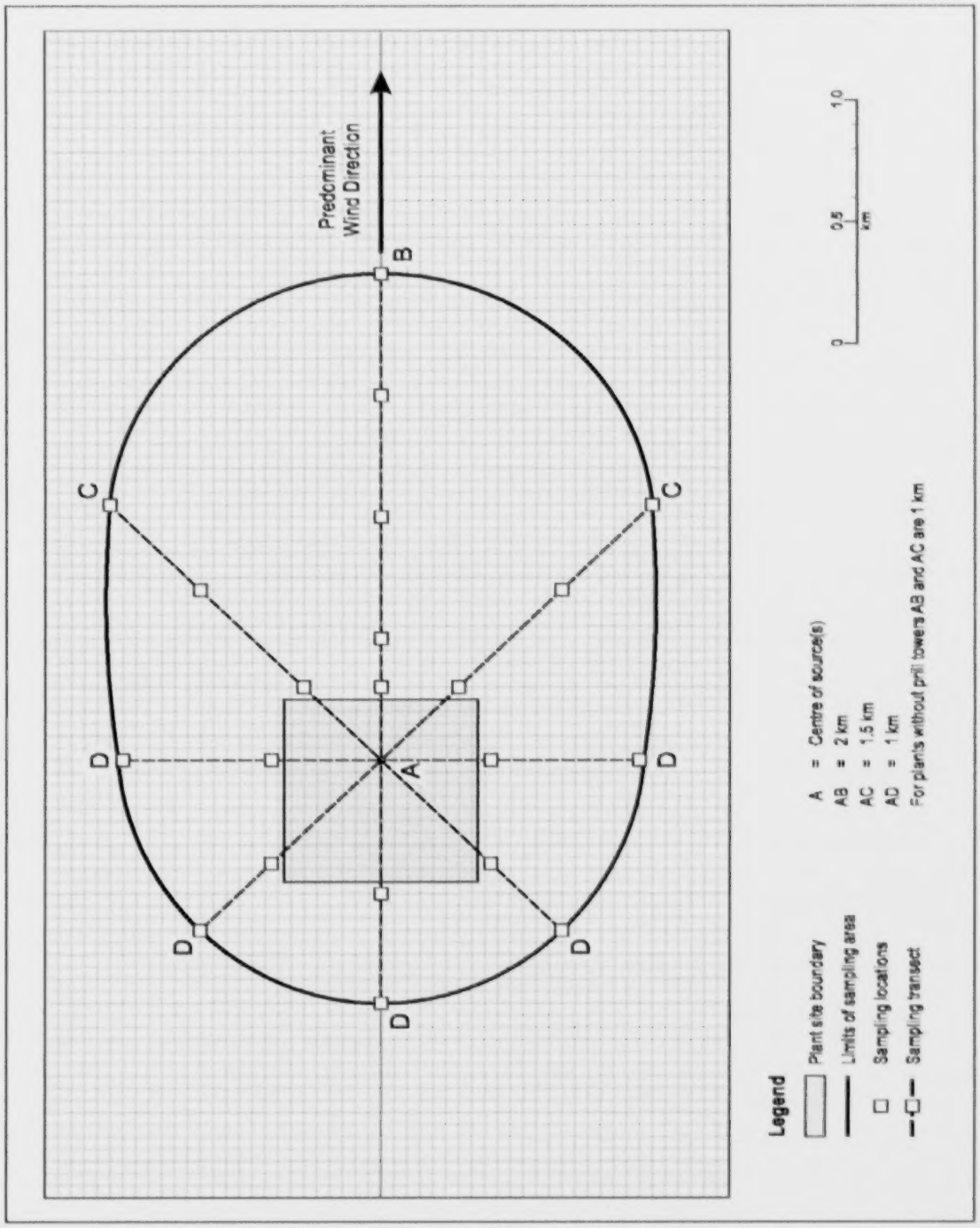
Local topography and land use may influence the deposition pattern. Where it can be done, modeling of potential deposition of sulphur dust in the vicinity of a plant may provide an alternative means for selecting sampling locations.

Sampling locations

The sampling locations defined by the radial transect design are based on the likelihood of deposition as determined by wind direction. Features specific to the local area must also be considered when they influence choice of sampling locations. For example, the presence of water bodies and limited accessibility may preclude sampling at a location defined by the radial transect design alone. Locations that are subjected to soil erosion or physical disturbance should be avoided. Sampling locations should include sensitive soils where they can be identified. All sampling locations should be a minimum of 50 m away from roadways. Sampling of organic soils should be avoided unless they represent a dominant soil type within the sampling area. The quality of soil samples from agricultural land may be compromised by fertilizer application and a record of the latter, when available, should be reported to assist in data interpretation. All sampling locations must be identified with a GPS device, and where possible, marked in the field as they will be used repeatedly in the subsequent Routine Monitoring Program.

When conducting soil sampling, the depth intervals defined in section 2.2.2.2 must be followed. For each depth interval a minimum of five separate soil samples must be collected within a 5 m radius of a sampling location. The samples must be composited within each depth interval for that location. Where it is possible, the composite samples should be mixed in the field.

Figure 2 Radial transect sampling design diagram



2.2.2.1 The approval holder shall conduct soil sampling for the Baseline Site Characterization Program in accordance with the following:

a) soil samples shall be collected from sampling locations defined by the radial transect design; and

b) the approval holder shall provide written justifications to the Director for any site-specific amendments to the radial transect design.

Sampling depth

The sampling depth must facilitate the detection of surficial deposition of sulphur dust and subsequent changes in soil properties. Since impact begins at the soil surface, the sampling should extend from the surface to a relatively shallow depth.

2.2.2.2 Soils sampled for the Baseline Site Characterization Program in section 2.2.2.1 shall be collected according to:

a) soil type and,

b) at a minimum, from the following depth-increments:

i) Organic soils: from 0 to 5 cm across a 10 x 10 cm sampling area;

ii) forest soils:

A) where the soil has a forest floor (LFH layer): from the top of the forest floor to the point of contact with mineral soil across a 10 x 10 cm sampling area and the thickness of forest floor, in cm, shall be recorded;

B) where the soil does not have a forest floor: from 0 to 5 cm of mineral soil;

iii) grassland: from 0 to 5 cm; and

iv) cultivated soils: from 0 to 15 cm.

2.2.3. Sample handling

Guidelines and procedures for handling of soil samples are provided by Sheppard and Addison (2008) for mineral soils or Maynard et al. (1994) for leaf litter (LFH) and organic soils.

2.2.4. Analytical parameters and methods

Baseline soil pH and total sulphur content are two parameters used to define operational thresholds in section 3.2.3.1 for evaluation of the impacts of sulphur deposition. Soil electrical conductivity (EC) is measured to determine baseline salinity level. Soil bulk density is required to convert the analytical data from concentration to mass per unit area, which is the unit used for measuring sulphur deposition. A list of recommended analytical methods of soil parameters for the Baseline Site Characterization and other programs of this *Directive* is provided in Table 1.

2.2.4.1 The approval holder shall analyze all soil samples collected for the Baseline Site Characterization Program, at a minimum, for all of the following:

a) pH;

b) total sulphur content; and

c) electrical conductivity.

Table 1 Recommended analytical methods

Soil Parameter	Recommended Method	Reference
1. Soil pH	$CaCl_2$ method for all Baseline Site Characterization Program and subsequent programs.	Hendershot et al. (2008). Use pH in water suspension only if it is maintained in previous events.
2. Total sulphur (S)	LECO oxidation or inductively coupled plasma-atomic emission spectrometry (ICP-AES) method.	Kowalenko (2001) and LECO instrument operational manual for LECO oxidation method, or Kalra and Maynard (1991) for ICP-AES method.
3. Elemental sulphur (S^o)	Extraction with chloroform for mineral soils, or with acetone for leaf litter or organic layers.	Watkinson et al. (1987) or Zhao et al. (1996) for the chloroform method, or Maynard and Addison (1985) for the acetone method.
4. Electrical conductivity (EC)	Saturation paste extract.	Miller and Curtin (2008).
5. Sulphate sulphur (SO_4^{2-})	Analysis of saturation paste extract.	Tabatabai (1996) or Kalra and Maynard (1991).
6. Bulk density	Core method for grassland and cultivated soils, excavation method for organic and forest soils.	Blake and Hartge (1986).
7. Calcium carbonate equivalent	Acetic acid dissolution method or CO_2 weight loss method.	Ashworth (1997).
8. Cation exchange capacity (CEC)	Unbuffered 1.0M NH_4Cl method.	Kalra and Maynard (1991).
9. Lime requirement	Shoemaker-McLean Pratt (SMP) Single-Buffer method to restore pH, or stoichiometric method to neutralize potential acidity from oxidation of elemental S.	Ziadi and Tran (2008) for SMP method or AENV (2011) for the stoichiometric method.
10. Molar ratio of Ca/Al, or molar ratio of base cations /Al in soil solution	Determination of Ca, Mg, K, and Al in the saturation paste extract.	Miller and Curtin (2008).
11. Other parameter(s) required in writing by the Director		As required in writing by the Director.

2.2.4.2 In addition to the requirements in section 2.2.4.1, the approval holder shall determine the soil bulk density at every depth increment for each of the sampling locations.

2.2.4.3 The approval holder shall adhere to the methods of analysis specified in Table 1, unless otherwise authorized in writing by the Director.

Where an approval holder wants to use an alternative analytical method for determination of any soil parameter listed in section 2.2.4, written justification for the alternative method must be provided to and approved by the Director before its use.

Soil calcium carbonate equivalent and cation exchange capacity (CEC) are parameters that influence the buffering capacity of soils and thus sensitivity to impact from deposition of sulphur dust. Measurement of these two parameters may be necessary to determine an appropriate liming rate in a Mitigation Program. Baseline sulphate concentration in soils is also useful for assessing the movement of sulphur derived from biological oxidation of sulphur dust.

2.2.5. Laboratory analysis requirement

2.2.5.1 The approval holder shall analyze all samples required by this Directive in a laboratory accredited pursuant to ISO/IEC 17025: General requirements for the competence of testing and calibration laboratories, as amended, for the specific parameter(s) to be analyzed, unless otherwise authorized in writing by the Director.

2.2.5.2 The approval holder shall ensure that the laboratory uses methods adopted and/or authorized by AEW, including but not limited to the methods in Table 1.

2.3. Requirements for the Baseline Site Characterization Program Report

The Baseline Site Characterization Program report must be submitted by the approval holder to the Director in conjunction with submission of the first Routine Monitoring Program report following whatever is the earlier in the schedule set out in section 3.3.2.1a or 3.3.2.1c of this *Directive*.

2.3.1.1 The Baseline Site Characterization Program report required in section 2.1.1.1 shall include, at a minimum, all of the following information:

Administrative information

a) document title identifying the Baseline Site Characterization Program report;
b) the business name of the approval holder for the plant;
c) the name, address and legal location of the plant;
d) date of the report;
e) the name of the environmental consulting firm and signature(s) of the environmental professional(s) who carried out the work;

Study area characteristics

f) a map and description of the plant site and adjacent land, including topography, surface drainage, surface water bodies, parent geological materials, vegetation and major land use prior to site disturbance;

g) a site plan, photo mosaic or aerial photograph at 1:25,000 scale or higher resolution identifying the proposed locations for sulphur manufacturing, processing or storage operations and points of potential release of sulphur dust;

h) the volume of sulphur (in tonnes per year) to be handled, handling methods and the planned block size when blocks are constructed;

i) a brief description of any previous release of sulphur in the sampling area;

Sampling locations and methods

j) a figure showing sampling locations within the radial transect design and indicating the predominant wind direction and source of potential release;

k) a table indicating the GPS coordinates, soil type as outlined in section 2.2.2.2 and sampling depth for each sampling location;

l) a description of the field quality assurance and quality control (QA/QC) procedures followed for collecting, handling, transporting and storing soil samples;

Results and discussion

m) a table presenting all analytical results including, at a minimum, soil pH, total sulphur content (kg S ha^{-1} soil) and EC for all sampling locations;

n) any other analytical results collected for samples such as but not limited to calcium carbonate equivalent, CEC and sulphate concentration;

o) an interpretation of all analytical results and their implications for the future Routine Monitoring Program, identifying any sampling locations on sensitive soils;

Appendices

p) a copy of laboratory data sheets related to sample analysis for this program; and

q) any other information requested in writing by the Director.

3. ROUTINE MONITORING PROGRAM

The Routine Monitoring Program must be carried out on a regular basis at operating plants that handle solid elemental sulphur. It provides on-going assessment of deposition of sulphur dust and its impact on soils in the vicinity of the plant. As monitoring histories of new plants and well-established plants will differ, so will some requirements among those plants.

3.1. Objectives of the Routine Monitoring Program

The objectives of the Routine Monitoring Program are to:

- identify locations where deposition of sulphur dust occurs,
- estimate the magnitude of impact, and
- trigger timely mitigation and management of impact.

3.1.1. Requirements for the Routine Monitoring Program

3.1.1.1. The approval holder shall conduct a Routine Monitoring Program on areas impacted and potentially impacted by deposition of sulphur dust in accordance with this Directive.

3.2. Program Design for the Routine Monitoring Program

The design of the Routine Monitoring Program is intended to identify the most likely locations of deposition of sulphur dust outside an operating plant. For a new sulphur handling and processing plant or a plant expansion, the radial transect design outlined in section 2.2.2 or that obtained from site-specific deposition modelling for the Baseline Site Characterization Program, must be used to conduct the first Routine Monitoring Program. At some operating plants an alternative sampling design approved by the Director may already be in place. Any records of past releases and results from previous Routine Monitoring Program events should be used to improve the program.

The approval holder must review relevant company records of solid sulphur manufacturing, processing or storage at the site, including but not limited to the following:

- type, volume and age of the sulphur manufacturing, processing or storage operation;
- releases of sulphur dust to soil, vegetation and other environmental media; and
- previous Baseline Site Characterization Program report(s), and other monitoring and mitigation reports for deposition of sulphur dust, if any, in the area surrounding the plant.

The approval holder should conduct interviews with staff who are knowledgeable about the history of the operation, previous sulphur releases and land owner concerns. The approval holder must conduct a site visit to locate areas of known and potential soil concerns related to sulphur manufacturing, processing or storage operation. Knowledge of local climatic, landscape and land use conditions should also be considered.

3.2.1. Soil sampling

All soil sampling locations used in the Baseline Site Characterization Program are typically included in the Routine Monitoring Program at a new plant or where a plant has expanded. For older plants, a set of sampling locations is likely already established for the Routine Monitoring Program. In some cases, adjustments in sampling locations may be necessary based on previous monitoring and mitigation events and additional background soil locations may be required.

The radial transect sampling design as illustrated in Figure 2 may be simplified for plants with reduced risk of sulphur dust deposition, such as a limited slating operation that does not have a prilling tower or a sulphur block. Similarly, when an approval holder has adopted low-emission technologies over the course of an approval period, the Routine Monitoring Program may adopt a simplified sampling design. In these cases, all transects may have a length of 1000 m. A simplified Routine Monitoring Program must include a transect downwind of the predominant wind direction and include at least five other transects. The sampling locations may be adjusted over the course of the Routine Monitoring Program to make it more effective.

The soil samples must be collected according to the soil types and depth intervals as outlined in section 2.2.2.2. For each depth interval a minimum of five separate soil samples must be collected within a 5 m radius of a sampling location and composited in a manner similar to that in section 2.2.2, as soil data collected in the Routine Monitoring Program must be compared against that from the Baseline Site Characterization Program. Soils should be sampled around the same time each year and under similar weather conditions. The period of August to October is considered most appropriate, assuming no snow cover is present. Care should be taken during each sampling event to minimize disturbance of the site as future sampling events will be undertaken at the same location.

Generally, soil samples should be handled and prepared as outlined by Sheppard and Addison (2008) for mineral soils or Maynard et al. (1994) for leaf litter (LFH) and organic soils. In addition, the entire sample must be thoroughly mixed prior to analysis because elemental sulphur tends to settle in transit. Additional precautions for handling sulphur-containing soils are provided by Watkinson et al. (1987), Zhao et al. (1996) and Kowalenko (2001).

3.2.2. Analytical parameters and methods

3.2.2.1 The approval holder shall analyze all soil samples collected in the Routine Monitoring Program, at a minimum, for all of the following:

a) pH;
b) total sulphur content;
c) electrical conductivity; and
d) elemental sulphur concentration.

3.2.2.2 The approval holder shall adhere to the methods of analysis specified in Table 1, unless otherwise authorized in writing by the Director.

For re-sampling events at a location that is not physically disturbed by construction or change in land use, the approval holder may use the soil bulk density data from previous reports for the

corresponding depth-intervals. Reducing sampling for soil bulk density should contribute to maintaining the integrity of the site for long-term monitoring.

3.2.3. Operational thresholds for mitigation

Data collected in the Routine Monitoring Program must be compared against those in the Baseline Site Characterization Program within corresponding depth-increments.

3.2.3.1. In order to determine if soil mitigation is required, the approval holder shall compare the temporal change in soil parameters from baseline conditions against the following operational threshold values:

a) a decrease of 1 unit or more in soil pH from the baseline conditions for Organic, forest, grassland or cultivated soils; or

b) an elemental sulphur concentration greater than 500 mg S kg^{-1} soil (AENV, 2010a, as amended); or

c) either an increase of 320 kg ha^{-1} or more of total sulphur above baseline in the litter layer or the 0 to 5 cm depth-increment of the Organic, forest and grassland soils; or an increase of 640 kg ha^{-1} or more in total sulphur content above baseline in the 0 to 15 cm depth-increment of cultivated soils, or

d) any other threshold values as specified in writing by the Director.

Measurement of soil pH indicates whether or not soil acidification has occurred. Elemental sulphur content only provides a measure of recent deposition of sulphur dust because elemental sulphur is readily oxidized to sulphate by soil bacteria in most aerobic soils. Investigation of sulphate content can provide insight on transformation of sulphur in impacted soils, aiding interpretation of data. Total sulphur content in soils provides a measure of the cumulative deposition of sulphur dust. Assessment of several parameters will provide better protection against impact to soil than reliance on any single parameter. All soil properties identified in section 3.2.3.1 must be determined in a Routine Monitoring Program event.

For some older plants where baseline soil data are not available, it is acceptable to use background locations as a surrogate baseline, provided that the locations are not affected by plant operations and the soil types are the same as the locations being monitored.

3.3. Monitoring and Reporting Schedule for the Routine Monitoring Program

3.3.1. Monitoring

3.3.1.1 Unless otherwise authorized in writing by the Director, the approval holder shall conduct the Routine Monitoring Program to assess the deposition of sulphur dust and its impact to soil, at a minimum, every other year starting in the first year of the approval.

3.3.2. Reporting

3.3.2.1 The approval holder shall submit to the Director a Routine Monitoring Program report in accordance with the following schedule, unless otherwise authorized in writing by the Director:

a) by May 15 of the fifth year of the approval;
b) by May 15 of the tenth year of the approval; and
c) by May 15 of the year following the first Routine Monitoring event that discloses the exceedance of the operational thresholds in section 3.2.3.1.

3.4. Requirements for the Routine Monitoring Program Report

3.4.1.1 The Routine Monitoring Program report required in section 3.3.2.1 shall contain, at a minimum, all of the following information:

Administrative information

a) document title identifying the Routine Monitoring Program report;
b) the business name of the approval holder for the plant;
c) the name, address and legal location of the plant;
d) the Routine Monitoring events to be reported as specified in section 3.3.2.1;
e) date of the report;
f) the name of the environmental consulting firm and signature(s) of the environmental professional(s) who carried out the work;

Study area characteristics

g) a map and description of the sampling area including topography, surface drainage, surface water bodies, parent geological materials, vegetation and major land use;
h) a site plan, photo mosaic or aerial photograph at 1:25,000 scale or higher resolution identifying the current locations for sulphur manufacturing, processing or storage operations and points of potential release of sulphur dust;
i) the current volume of sulphur (in tonnes per year) handled, the type and age of handling operations that may influence the amount of sulphur dust emission and deposition;
j) a brief description of any previous release of sulphur in the sampling area;

Sampling locations and methods

k) a figure showing sampling locations within the radial transect sampling design, or an alternative sampling design, and indicating the predominant wind direction and source of release;
l) a brief discussion of any changes in the sampling design from the Baseline Site Characterization Program or the last Routine Monitoring Program report;
m) a table indicating GPS coordinates, the soil type as outlined in section 2.2.2.2 and sampling depth for each sampling location;

n) *a description of the field quality assurance and quality control (QA/QC) procedures followed for collecting, handling, transporting and storing soil samples;*

Results and discussion

o) *a table presenting all analytical results including at a minimum, pH, EC, total sulphur content (kg S ha^{-1} soil), elemental sulphur content (mg S kg^{-1} soil) at each sampling location for those Routine Monitoring events in each reporting period specified in section 3.3.2.1;*

p) *a table presenting the differences in pH and total sulphur content (kg S ha^{-1}) from the baseline, and the elemental sulphur content for all sampling locations for those Routine Monitoring events in each reporting period specified in section 3.3.2.1, highlighting all values that exceed the operational threshold values in section 3.2.3.1;*

q) *figure(s) illustrating the long term trends in soil pH, total sulphur content (kg ha^{-1}) and elemental sulphur concentration (mg kg^{-1}) in the soil since the beginning of the monitoring program, including where available, the baseline soil data;*

r) *a brief interpretation of the monitoring results identifying any observed long-term trends in measured parameters and confirming whether or not a Mitigation Program Plan is required pursuant to sections 3.2.3.1 and 4.2.1.1;*

s) *a brief discussion of mitigation activities at any sampling locations;*

Appendices

t) *a copy of laboratory data sheets related to sample analysis for this program; and*

u) *any other information requested in writing by the Director.*

4. MITIGATION PROGRAM

A Mitigation Program is required at plants that handle solid elemental sulphur where the results of any Routine Monitoring Program event indicate that one or more of the operational threshold values in section 3.2.3.1 have been exceeded.

4.1. Objectives of the Mitigation Program

The objectives of the Mitigation Program are to:

- identify and manage, to the extent possible, all sources of release of sulphur dust;
- delineate the spatial extent of the impact at each sampling location on the radial transect design, or an alternative sampling design, where the operational threshold values in section 3.2.3.1 are exceeded;
- mitigate impacts to soil and associated media; and
- assess the progress of mitigation through confirmatory sampling.

As indicated above, a Mitigation Program will usually have four components: source control, delineation, soil treatment and confirmatory sampling. Source control is of primary importance in managing the impact of sulphur dust on soils. Delineation is intended to define the spatial extent of impact to soil and other associated media and to inform soil treatments. Soil treatment is intended to reverse soil acidification and reduce adverse effects. Confirmatory sampling will indicate whether or not mitigation has been effective and, if so, may lead to closure of the Mitigation Program.

In some situations soil may not return to baseline conditions. For example, it may be very difficult to return the full depth of severely impacted fine-textured forest soils to baseline conditions. In such cases, AEW expects the approval holder to adopt an adaptive management approach by setting alternative mitigation targets. Alternative mitigation targets should be defined through a risk management approach according to the general principles found in the *Alberta Tier 2 Soil and Groundwater Remediation Guidelines* (AENV, 2010b), as amended. When an alternative approach is to develop a risk management program to address impacts, it must incorporate guidance provided in this *Directive* too.

The development and implementation of the Mitigation Program must include communication with stakeholders, such as landowners. When soil mitigation on Crown Land is planned, the Alberta Sustainable Resources Development (ASRD) must be notified. If an approval holder needs to develop a risk management program to address severe and extensive impacts, the risk management program needs be accepted by all stakeholders prior to its implementation.

While this *Directive* focuses on soils, AEW expects approval holders to mitigate impacts to other media as well. Guidance may be obtained from references listed in this *Directive* and/or other regulatory agencies. For example, ASRD must be contacted for mitigation of impacts to vegetation and wildlife habitats on Crown Land in Alberta.

4.2. Requirements for the Mitigation Program

4.2.1.1 When one or more of the operational threshold values in section 3.2.3.1 are exceeded, the approval holder shall submit a Mitigation Program Plan to the Director by May 15 of the year following the first Routine Monitoring Program event that discloses the exceedance, unless the approval holder has received written authorization from the Director waiving this requirement.

4.2.1.2 The Mitigation Program Plan referred in sections 3.4.1.1 and 4.2.1.1 shall include, at a minimum, all of the following information:

- *a) an appropriate figure and table with analytical results identifying those locations in the Routine Monitoring Program where threshold values were exceeded;*
- *b) a description of any measures that have or will be taken to control the source of the release;*
- *c) a description of the delineation protocol to be employed including soil sampling locations, sampling depth(s) and analytical measurements;*
- *d) a description of the remedial actions planned;*
- *e) a schedule of source control, delineation, soil treatment and confirmatory sampling activities; and*
- *f) a description of alternative remediation objectives and risk management program, if required, when the soil cannot be returned to baseline conditions.*

4.3. Possible Strategies for Source Control

A contaminant is a substance that is present in an environmental medium in excess of natural background concentration (CCME, 2006). A source of contamination is anything that adds contaminant mass to the environment. Source control is a crucial step in pollution prevention under Alberta's framework for management of contaminated sites. The *Alberta Tier 1 Soil and Groundwater Remediation Guidelines* (AENV, 2010a) state that "if there is evidence of soil or groundwater contamination, the source, if it is still present, must be identified. Sources must be removed or controlled as soon as practicable". Source control is also identified in the *Soil Monitoring Directive* (AENV, 2009) as an important step in managing soil contamination at approved facilities.

In practice, source control often starts with identification of all potential sources for release at the plant. For most industrial sites, review of operational processes is an important part of source identification. Some sources of sulphur dust are associated with common sulphur processing and handling practices and may be controlled accordingly. To reduce release of sulphur dust, loading, unloading and block-breaking must be avoided on windy days. Storage facilities for sulphur must be shielded from wind. Removal of large volumes of sulphur-contaminated waste at the plant site helps eliminating potential sources. Source control is often most effectively achieved by adopting lower emission technologies (Crawford, 2009) such as rotoforming or GX granulation. As previously stated, AEW expects approval holders to continually improve their operations and use the best available technologies to minimize release of sulphur dust and reduce the cumulative impacts to the environment. Guidance regarding the disposal of sulphur wastes

from the plant site can be obtained in the *Guidelines for Landfill Disposal of Sulphur Waste and Remediation of Sulphur-Containing Soils* (AENV, 2011), as amended.

4.4. Strategies for Delineation

The purpose of delineation is to identify the spatial extent of impacts at sampling locations in the Routine Monitoring Program. Field approaches for delineation need to consider substance mobility, transport and fate along with relevant exposure pathways and receptors. Depending on the specific purpose of a delineation project, different approaches and intensity levels may be required. The *Alberta Tier 1 Soil and Groundwater Remediation Guidelines* (AENV, 2010a) require complete delineation of an impacted zone prior to implementation of mitigation.

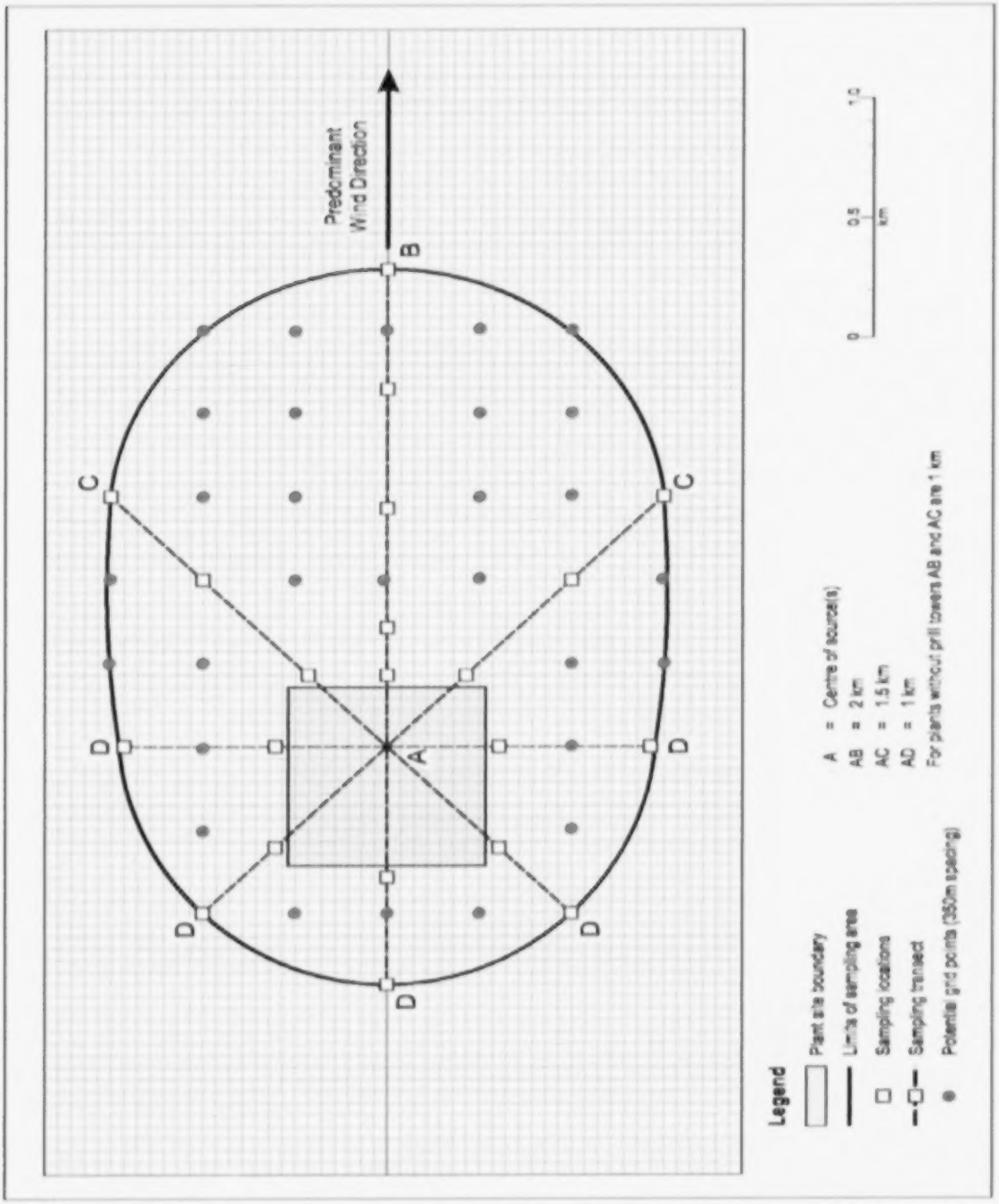
A grid sampling design has been used in Alberta for delineating the impacts to soil from deposition of sulphur dust. The general layout of the grid sampling design is illustrated in Figure 3. Delineation should start with each location in the Routine Monitoring Program where the operational threshold values in section 3.2.3.1 are exceeded. A spacing of approximately 350 m between grid points is recommended. Delineation must define the extent of the impacted areas to which mitigation will be applied. Field observations may assist in delineation. Visual inspection may identify recent deposition, although sulphur dust may be confused with pollen in spring and early summer. Appearance of stressed, stunted or dead vegetation, or changes in plant community composition, may also indicate impact. Some approval holders have an extended monitoring and mitigation history that may require modifications to the grid sampling design. Where certain site conditions require an approval holder to use an alternative delineation scheme, written justification must be provided to the Director within the Mitigation Program Plan.

Where impact is suspected below the surface depth-increment, vertical delineation must be conducted. Soil sulphate concentration is an effective parameter for determining vertical delineation because sulphate readily leaches down in soils. The surface soil depth-intervals defined in section 2.2.2.2 for Baseline Site Characterization are useful for identifying shallow impact. For mineral soils that have a litter or sod layer, delineation should, at the least, extend into the first underlying mineral soil horizon. When delineating deeper contamination where no baseline data are available to define impacts, the approval holder will need to rely on background soils as a surrogate of baseline. The severity of impact, mobility of sulphur compounds, soil types, drainage characteristics, and groundwater table may also affect the depth of impact, and hence the depth of delineation required. Alberta Environment and Water expects approval holders and their consultants to exercise due diligence and professional judgment in delineation of impact.

4.4.1. Soil sampling for delineation

Field inspection and screening for delineation of impact from sulphur dust may or may not lead to soil sampling. Where soil sampling for laboratory analysis is required, the GPS coordinates of all sampling locations must be determined. Where possible, sampling locations should also be marked in the field as some sampling locations will be repeatedly sampled to assess the progress of mitigation. Soil samples for laboratory analysis must be handled and prepared in a similar manner as outlined in section 3.2.1.

Figure 3 Typical grid sampling design diagram



4.4.2. Interpretation of analytical parameters for delineation

The soil samples collected in delineation must be analyzed, at a minimum, for soil parameters outlined in section 3.2.2. For locations included in the Routine Monitoring Program, the delineation results are interpreted by comparison against baseline values as required by section 3.2.3.1, or against background values when delineation is conducted at locations where baseline information is not available. The delineation protocol must clearly explain how the parameters outlined in section 3.2.2 and any additional parameters are used to address the objectives of delineation.

4.5. Soil Treatment

When soils are impacted by deposition of sulphur dust as defined in section 3.2.3.1, treatment is required to reverse soil acidification. Methods and materials to treat soil acidification are described in the literature, including Barber (1984), Nilsen (1994) and Havlin et al. (1999). Among the various liming materials, calcium carbonate ($CaCO_3$) is most commonly applied. Quicklime (CaO) and hydrated lime ($Ca(OH)_2$) are difficult to handle and not recommended because they may cause damage to vegetation or raise the pH in some soils above optimal for crop production and forest growth. Agricultural grade limestone is often used to remediate impact. Lime materials that pass through a 60 mesh sieve are proven effective in treating soil acidification in North America (Barber, 1984; Havlin et al., 1999). Approval holders should examine the specifications of a lime product before conducting soil treatment. About 90% of the finely ground limestone powder should pass through a 60 mesh sieve and magnesium carbonate ($MgCO_3$) content of limestone should not exceed 2% by weight in order to reduce risk of soil salinization.

Methods to determine liming rates may vary with the mitigation objectives. Where the soil pH remains close to baseline conditions, the objective of liming is to neutralize the potential acidity that will be generated by microbial oxidation of elemental sulphur. In this case, the liming rate can be determined by multiplying the amount of elemental S presented (kg ha^{-1}) by a stoichiometric conversion factor of 3.2 (AENV, 2011). Where soil pH is markedly depressed relative to baseline and surface accumulation of sulphur dust is minimal, the liming rate may be determined by empirical laboratory procedures set out by Ziadi and Tran (2008).

The method of lime application varies with land use. On cultivated land, lime materials are normally incorporated into the cultivated layer of soils to speed mitigation. The timing for application should be optimized to avoid machinery compaction to soil and excessive lime dust to the local area. Approximately half a year is required for lime to take effect. Over-liming with a high dose (greater than 7 to 9 tons ha^{-1}) must be avoided (Brady and Weil, 1999). Where a large amount of lime is necessary to correct severe impacts, it should be divided into several smaller doses and applied in multiple years. Liming for impacted forest soils is more challenging. Limited machinery access and the presence of vegetation across the ground surface preclude mechanical incorporation of the lime into soil. Surface application of ground limestone ($CaCO_3$) to the forest floor is commonly used to mitigate forest soils impacted from acid deposition in Europe (Kreutzer, 1995). In Alberta, agricultural grade limestone has proven effective in treating soil impacted by deposition of sulphur dust near industrial facilities. Large

areas with limited access may be treated by aerial application, while small areas with good access may be treated by hand-spreading. The ground limestone material should not get wet prior to application because it is difficult to apply the wet limestone material evenly. Over-liming needs to be avoided because most plant species in the Northern Forested Region and Eastern Slopes Region of Alberta are adapted to slightly acidic or acidic soil environments.

Approval holders are responsible for developing effective soil treatments within their Mitigation Program Plan. In selecting the method and rate of lime application, all factors discussed in this *Directive* must be considered. Application of lime can be both beneficial and detrimental to vegetation and associated watersheds (Löfgren et al., 2009; Kreutzer, 1995). The liming treatment selected must maximize the benefits while minimizing potential negative effects. Where agricultural limestone is not used as the soil treatment material, written justification for use of alternative materials as well as a complete description of the methodology must be provided to the Director.

4.6. Confirmatory Sampling

4.6.1. Soil sampling

Soil samples must be collected from areas that have received lime application to confirm whether mitigation has been effective. The preferred sampling period is from August to October, consistent with the Routine Monitoring Program. As changes in soil properties are often gradual due to the limited solubility and mobility of active gradients of lime (Barber, 1984), adequate time should be allowed for lime application to take effect in soil before collecting confirmatory samples. Changes in the forest floor layer may be expected within 2 to 6 years and may take longer in mineral horizons (Kreutzer, 1995) and other media (Löfgren et al., 2009).

The selection of locations and depth intervals for confirmatory sampling will depend on the spatial extent of treatment. In general, a minimum of five separate soil samples for each depth interval need to be collected at each sampling location. These depth intervals are described in section 2.2.2.2. Composite samples within each depth interval must be prepared similarly to that in section 2.2.2. Soil samples must be handled and prepared as outlined in section 3.2.1.

4.6.1.1. The approval holder shall conduct confirmatory soil sampling events and analyze the samples, at a minimum, once every two years, commencing the year that follows the first year when mitigation treatments described in the Mitigation Program are implemented.

4.6.2. Analytical parameters and their interpretation for confirmatory sampling

Choice of analytical parameters for confirmatory samples depends on the mitigation targets. Baseline information, when and where available, can be used to define mitigation objectives. In these instances measurement of pH, total sulphur content, elemental sulphur content and EC in a manner similar to the Routine Monitoring Program, will be informative. Measurement of elemental sulphur content in confirmatory samples can be used to assess progress in source control. The results must be compared with the elemental sulphur content of 500 mg kg^{-1} found in the *Alberta Tier 1 Soil and Groundwater Remediation Guidelines* (AENV, 2010a), as

amended. Measurement of EC can assess the risk of soil salinization following liming. Most plant species and crops are adversely affected when EC values are greater than 4 dS m^{-1}.

Where impacts are severe and soil may not return to baseline conditions, alternative mitigation objectives may need to be defined and additional analytical parameters may be necessary. An alternative mitigation objective may be the assessment of the risk of metal toxicity to vegetation because soil acidity is primarily experienced by plants as aluminum (Al) toxicity (Godbold et al., 1988; Robarge and Johnson, 1992; Cronan and Grigal, 1995). The latter can be measured by the molar ratio of calcium (Ca) to Al in soil solution of forest soils or the molar ratio of base cations (Ca, magnesium (Mg) and potassium (K)) to Al in soil solution of grassland or cultivated soils (Cronan and Grigal, 1995; Turchenek and Abboud, 2001; and Kwak et al., 2009).

4.7. Managing Outcomes of the Mitigation Program

Some impact of sulphur dust to soils may be simpler to manage while others are more challenging. In general, impact on agricultural soils is easier to manage than on forest soils. Impact to the uppermost soil horizon is simpler to manage than to subsoil. Change of total sulphur content is often slower in fine textured soils than in coarse-textured soils.

4.7.1. Possible targets in different phases of a Mitigation Program

When effective measures are implemented to control the source of release of sulphur dust, elemental sulphur content on the land surface is expected to decline. When lime can be incorporated into cultivated soil, pH of the uppermost horizons should recover toward the baseline within a reasonable period of time. For impacted underlying horizons, the Ca to Al ratio in forest and organic soils, or exchangeable base cations to Al ratio for cultivated and grassland soils may recover faster than pH. The total sulphur concentration in soil is likely to change much slower, given that most Alberta soils experience some level of moisture deficit due to climatic conditions. The different outcomes of a Mitigation Program must be managed accordingly.

The following short-term outcomes are expected from Mitigation Programs:

- a steady decline in deposition of sulphur dust, so that elemental sulphur content in soils in each of the three most recent confirmatory sampling events is less than the Alberta Tier 1 guideline value of 500 mg kg^{-1}; and
- a return to the baseline pH in the uppermost horizons of all soil types.

For underlying soil horizons and slow-to-recover soil parameters, long-term mitigation measures need to be considered. For example, the Mitigation Program may be adjusted to minimize the toxicity of Al by increasing the molar ratio of Ca to Al greater than 1 for forest and organic soils or molar ratio of base cations (Ca, Mg and K) to Al greater than 45 for grassland and cultivated soils. Following that, the frequency and dose of lime application may be further adjusted to avoid the risk of over-liming in the uppermost horizons. A phased approach in a Mitigation Program should allow approval holders to achieve as many short-term outcomes as possible during plant operation, thereby reducing residual impacts to soils at plant decommissioning.

More stringent values of the Ca to Al ratio or base cations to Al ratio may apply where sensitive plant species, sensitive soils or stringent land use requirements are present. The approval holder needs to conduct additional mitigation work if the impacts of sulphur dust have spread to groundwater or surface water.

4.7.2. Adaptive management for the Mitigation Program

The overall Mitigation Program is likely to be dynamic and may shrink or expand with time depending on source control and soil treatment at impacted locations. An adaptive management approach is needed to build and deliver an effective Mitigation Program Plan. On an area-by-area basis, the approval holder may discontinue mitigation activities where mitigation targets have been met. If the treated areas are impacted in the future, they must be included again in a Mitigation Program. An effective Mitigation Program Plan must also be flexible enough to accommodate any new locations where impact is identified in subsequent Routine Monitoring Program events within a given reporting period as outlined in section 4.8.1.1. If all impacted areas are mitigated and analytical results are below the operational threshold values set out in section 3.2.3.1, a written notification to the Director must be included in the Mitigation Program report for the reporting period in section 4.8.1.1. Subject to written acceptance from the Director, the Mitigation Program may be suspended.

At the end of plant operation, the approval holder must ensure that all impacted soil and related media are appropriately managed and remediated to meet the applicable Alberta Tier 1 or Tier 2 guidelines for the appropriate end land use.

4.8. Requirements for the Mitigation Program Report

4.8.1.1. The approval holder shall submit the Mitigation Program report to the Director in accordance with the following schedule, unless otherwise authorized in writing by the Director:

- *a) by May 15 of the fifth year of the approval for all delineation, treatment and confirmatory sampling events completed in that period; and*
- *b) by May 15 of the tenth year of the approval for all delineation, treatment and confirmatory sampling events completed in that period.*

4.8.1.2. The Mitigation Program report shall contain, at a minimum, all of the following information:

Administrative information

- *a) document title identifying the Mitigation Program report;*
- *b) the business name of the approval holder for the plant;*
- *c) the name, address and legal location of the plant;*
- *d) date of the report;*
- *e) the name of the environmental consulting firm and signature(s) of the environmental professional(s) who carried out the work;*

Measured impact and mitigation approach

f) an appropriate figure identifying those locations in the Routine Monitoring Program where impact occurred, including any locations added since the inception of the Mitigation Program, and a table of analytical results for parameters that exceeded the operational threshold values in section 3.2.3.1;

g) a description of the delineation protocol;

h) a table summarizing the GPS coordinates, soil types and sampling depth(s) for all sampling locations included in the delineation program;

i) a description of the mitigation objectives, including any alternative mitigation objectives;

j) an explanation and sample calculation of how the application rate of lime was determined;

k) a description of the spatial extent, rate, method and date of lime application;

l) a description of any alternative mitigation activities carried out in the field;

m) a description of confirmatory sampling methods and analytical parameters;

Program Results

n) identification of all sources of sulphur dust and a description of any measures taken to control the sources of the release;

o) a figure indicating where delineation has occurred and a table of analytical results;

p) a figure indicating where lime application has been made and where alternative mitigation activities, if any, were carried out;

q) a figure indicating where confirmatory sampling has occurred and a table of analytical results, highlighting any values that meet the possible mitigation targets in section 4.7;

r) a figure indicating those areas where the remediation objectives have been achieved;

s) a brief interpretation of the effectiveness of the Mitigation Program;

t) a brief description of the delineation and remedial activities, if any, scheduled for the next reporting period;

Appendices

u) a copy of laboratory data sheets related to sample analysis for this program; and

v) any other information requested in writing by the Director.

REFERENCES

AENV (Alberta Environment), 2011. Guidelines for Landfill Disposal of Sulphur Waste and Remediation of Sulphur-Containing Soils. Science and Technology Division, Alberta Environment, Edmonton, AB. Available on-line at: http://environment.gov.ab.ca/info/library/7417.pdf

AENV (Alberta Environment), 2010a. Alberta Tier 1 Soil and Groundwater Remediation Guidelines. Climate Change, Air and Land Policy Branch, Alberta Environment, Edmonton, AB. Available on line at: http://environment.alberta.ca/02196.html.

AENV (Alberta Environment), 2010b. Alberta Tier 2 Soil and Groundwater Remediation Guidelines. Climate Change, Air and Land Policy Branch, Alberta Environment, Edmonton, AB. Available on line at: http://environment.alberta.ca/01074.html.

AENV (Alberta Environment), 2009. Soil Monitoring Directive. Climate Change, Air and Land Policy Branch, Alberta Environment, Edmonton, AB. Available on-line at: http://environment.alberta.ca/3523.html

AENV (Alberta Environment), 1989. Air Monitoring Directive: Monitoring and Reporting Procedures for Industry. Standards and Approvals Division, Environmental Protection Services, Alberta Environment, Edmonton, AB. Available online at: http://environment.alberta.ca/632.html

Ashworth, J., 1997. Improvements to two routine methods for $CaCO_3$ determination in soils. Commun. Soil Sci. Plant Anal. 28:841-848.

Barber, S. A., 1984. Liming materials and practices. Pages 171-209 in Adams F. edited Soil Acidity and Liming, 2nd edition, ASA, CSSA and SSSA Inc., Madison, WI.

Blake, G.R. and Hartge, K.H., 1986. Bulk density. Pages 363-375 in Klute A. edited Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods, 2nd edition, ASA, SSSA Inc., Madison, WI.

Brady, N.C. and Weil, R.R., 1999. The Nature and Properties of Soils. 12th edition, Apprentice-Hall, Inc., Upper Saddle River, NJ.

CCME (Canadian Council of Ministers of the Environment), 2006. A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines. PN 1332. Canadian Council of Ministers of the Environment, Winnipeg, Manitoba. Available on-line at: http://www.ccme.ca/assets/pdf/sg_protocol_1332_e.pdf.

CEMA (Cumulative Environmental Management Association), 2004. Recommendations for the Acid Deposition Management Framework for the Oil Sands Region of North-East Alberta. Available online at: CEMA - Acid Deposition Management Framework.

Crawford, P., 2009. Are we there yet? Hydrocarbon Engineering, October 2009. Available online at: http://www.enersul.com/html/ELP_Articles_Resources_20091207124327.pdf.

Cronan, C.S. and Grigal, D.F., 1995. Use of calcium/aluminium ratios as indicators of stress in forest ecosystems. J. Environ. Qual. 24:209-226.

Environmental Protection and Enhancement Act, R.S.A. 2000, c.E-12. Available on-line at: http://www.qp.alberta.ca

ERCB (Energy Resources Conservation Board), 2010. ERCB ST101-2010: Sulphur recovery and sulphur emissions at Alberta sour gas plants–Annual report for the 2009 operating year, July 2010. Available online at: http://www.ercb.ca/docs/products/STs/st101_current.pdf.

Godbold, D.L., Fritz, E. and Hüttermann, A., 1998. Aluminium toxicity and forest decline. Proc. Natl. Acad. Sci. USA. 85:3888-3892.

Havlin, J.L., Beaton, J.D., Tisdale S.L. and Nelson, W.L., 1999. Soil Fertility and Fertilizers – An introduction to nutrient management. 6th ed., Prentice Hall Inc., New Jersey.

Hendershot, W.H., Lalande, H. and Duquette, M., 2008. Soil reactions and exchangeable acidity. Pages 173-178 in Carter, M.R. and Gregorich, E.G. edited Soil Sampling and Methods of Analysis. 2nd edition, CSSS, CRC Press, Boca Raton.

ISO/IEC 17025, General requirements for the competence of testing and calibration laboratories. Ordering information available on-line at: http://www.scc.ca

Kalra, Y.P. and Maynard, D.G., 1991. Method Manual for Forest Soil and Plant Analysis. Northern Forestry Centre, Forest Canada. Edmonton, AB. Also available online at: http://cfs.nrcan.gc.ca/pubwarehouse/pdfs/11938.pdf.

Kowalenko, C.G., 2001. Assessment of Leco CNS-2000 analyzer for simultaneously measuring total carbon, nitrogen, and sulphur in soils. Commun. Soil Sci. Plant Anal. 32:2065-2078.

Kreutzer, K., 1995. Effects of forest liming on soil processes. Plant and Soil, (168-169): 447-470.

Kwak, J.-H., Lim, S.-S., Park, H.-J., Lee, S.-H, Lee, K-H., Kim H.-Y., Chang, S.X., Lee, S.-M., Ro, H.-M., and Choi, W.-J., 2009. Relating tree ring chemistry of pinus densiflora to precipitation acidity in an industrial area of South Korea. Water Air Soil Pollut. 199:95-106.

Löfgren, S., Cory, N., Zetterberg, T., Larsson P.-E. and Kronnäs, V., 2009. The long-term effects of catchment liming and reduced sulphur deposition on forest soils and runoff chemistry in southwest Sweden. For. Ecol. Manage. 258:567-578.

Maynard D.G. and Addison, P.A., 1985. Extraction and colorimetric determination of elemental sulphur in organic horizons of forest soils. Can. J. Soil Sci. 65:811-813.

Maynard, D.G., Stadt, J.J., Mallett, K.I. and Volney W.J.A., 1994. Sulfur impacts on forest health in west-central Alberta. Information report NOR-X334, Canadian Forest Service, Northwest Region, Northern Forest Centre, Edmonton, AB. Also available online at: http://cfs.nrcan.gc.ca/pubwarehouse/pdfs/11938.pdf.

Miller, J.J. and Curtin, D., 2008. Electrical conductivity and soluble ions. Pages 161-171 in Carter M.R. and Gregorich E.G. edited Soil Sampling and Methods of Analysis. 2nd edition, CSSS, CRC Press, Boca Raton.

Nilsen, P., 1994. Proceedings from an international seminar on counteractions against acidification in forest ecosystems. March 3-4, 1994, Mastemyr, Norway. Norwegian Forest Research Institute (NISK).

Robarge, W.P. and Johnson, D.W., 1992. The effects of acidic deposition on forested soils. pages 1-83, in Sparks D.L. edited Advances in Agronomy, Vol. 47. Academic Press, Inc., San Diego.

Sheppard S.C. and Addison, J.A., 2008. Soil sample handling and storage. Pages 39-49, in Carter M.R. and Gregorich E.G. edited Soil Sampling and Methods of Analysis. 2nd edition, CSSS, CRC Press, Boca Raton.

Tabatabai, M.A., 1996. Sulfur. Pages 921-960 in Sparks, D.L. et al. edited Methods of Soil Analysis. Part 3 – Chemical Methods. SSSA Book Series No. 5. SSA and ASA Inc., Madison, WI.

Turchenek, L.W. and Abboud, S.A., 2001. Site-specific critical loads of acid deposition on soils in the Provost-Esther area, Alberta. Alberta Environment. Edmonton, AB. Also available online at: http://www.assembly.ab.ca/lao/library/egovdocs/alen/2001/136248.pdf.

Watkinson, J.H., Lee, A. and Lauren, D.R., 1987. Measurement of elemental sulphur in soil and sediments: field sampling, sample storage, pretreatment, extraction and analysis by high-performance liquid chromatography. Aust. J. Soil Res. 25:167-178.

Zhao, F.J., Loke, S.Y., Crosland, A.R. and McGrath, S.P., 1996. Method to determine elemental sulphur in soils applied to measure sulphur oxidation. Soil Biol. Biochem. 28:1083-1087.

Ziadi, N. and Tran, T.S., 2008. Lime requirement. Pages 129-134 in Carter M.R. and E.G. Gregorich edited Soil Sampling and Methods of Analysis. 2nd edition, CSSS, CRC Press, Boca Raton.